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A REMOTE INDICATING HINGE-MOMENT BALANCE

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SUMMARY

This report describes an electrical hinge-moment balance for use with wind-tunnel models of aircraft. A brief description of the principle of operation and operating experience with the balance is given in part I. Part II gives constructional details and part III gives theoretical considerations. Extensive constructional information is given to enable the reproduction of the equipment.

PART I. GENERAL DESCRIPTION

A. Introduction

In some wind-tunnel tests on aircraft models it is desired to determine the hinge-moment coefficients of the control surfaces. The methods usually used to date have involved either a determination of pressure distribution on the surface, or an auxiliary wire balance rigged to the model, to obtain sufficient data. Both of these methods involve a lengthy test procedure and increase the time during which the wind tunnel is inactive and is not available for other test work. Remote indicating electrical balances had been used by the NACA for the measurement of hinge moments, but it was thought advisable to develop a smaller measuring head or gage unit which could be more conveniently installed in models of the size used in the 7- by 10-foot tunnel.

An electrical hinge-moment balance has been developed which may be used while other test data on the complete model are being taken. It is small enough for the gage unit to be mounted in the tail cone of smaller models and to be completely concealed in the control surface when larger models are used. The unit is installed before the model is placed in the tunnel and the connections brought out through a multiconductor cable and connector. After the initial adjustments have been made, it is only necessary to record the indication of a large fan-type meter to determine the corresponding hinge moment from a calibration curve.

Work is now in progress on the development of a multisensitivity, multichannel apparatus for the measurement of the moments at a number of points and for the measurement, by an extension of the method, of motor torque in powered models.

B. Principle of Operation

In the electrical hinge-moment balance the load on the surface is transmitted to the model proper through a stiff spring. This spring deflects under the load, and the gage unit with its associated equipment measures this deflection. Because the deflection of the spring is used as a measure of the hinge moment, the spring and its linkage should be so designed that the motion is independent of such factors as model attitude, model loading (other than that of the surface under test), temperature, and previous load conditions. This is discussed at greater length under the design of the gage unit.

The gage unit itself is a transformer with the coupling between primary and secondary controlled by the motion of the spring. At the operator's position is a similar transformer with adjustable coupling. These two small transformers are connected to a source of alternating current supplying approximately 10 volts at 2000 cycles per second. The secondary coils of the transformers are connected so as to be in series opposition. The coupling of the unit at the operator's position (called the balance unit) can be adjusted to make the secondary voltage of the balance unit equal to that of the gage. Under this circumstance, where the voltages in the respective secondaries are equal in magnitude and opposed in phase, the resultant of the secondary voltages is zero. In practice a vacuum tube voltmeter serves to determine the difference between the two secondary voltages. It is clear that if the two units are in balance in this way at zero applied hinge moment any unbalance voltage resulting from a change in coupling at the gage unit is indicated on the voltmeter. Such a change in coupling is a result of a change in hinge moment if the precautions mentioned above have been observed.

Certain precautions must be taken with a gage of this nature for satisfactory operation as a deflection-type instrument. The oscillator used as the source of alternating current should show little drift in frequency and voltage. ~~The vacuum tube voltmeter should be sufficiently~~

~~voltage~~. The vacuum-tube voltmeter should be sufficiently sensitive and stable in calibration. The gage and leads should be shielded so that stray fields such as are caused by the motors in powered models will not introduce error. These requirements have been met by the use of stabilized voltage supplied for the oscillator and voltmeter and a choice of suitable circuits.

The block diagram (fig. 1) indicates the arrangement of the balance parts into the four chief components: the gage unit, the control box, the main chassis, and the voltage regulator. The gage unit transformer is located at the model and the wiring is brought back to the control box in two shielded cables. At the control box the gage is connected to the oscillator which supplies the alternating voltage and to the balance unit. The difference voltage can be controlled by the vernier adjustment on the balance unit. This setting is usually made to give a mid-scale reading on the output voltmeter. In this way a slight change in the gage voltage output will be readily identifiable as caused by either positive or negative hinge moment. If the initial setting were made to give a zero reading on the voltmeter, then a small change in the gage output voltage would cause an up-scale reading on the meter. However, there would be no way of telling whether or not the spring deflection was such as to cause the coils of the gage unit to move together as would be caused by positive moment or apart as caused by negative moment. When the coils are initially set to give an up-scale reading, and when the gage coils move together, the gage output goes up, and the difference voltage increases. Conversely, when the coils move apart, the gage output goes down and the difference voltage decreases.

The difference voltage is fed from the coils into a control and check circuit. In this circuit two separate functions are performed: the sensitivity is set by a resistance shunted across the coils, and a check circuit which indicates variations from the initial calibration is provided. A vernier adjustment on the oscillator voltage can be set to eliminate these variations if caused by drifts in oscillator voltage or frequency, or in amplifier gain. This insures constancy of calibration. The oscillator voltage may be set approximately with a control resistor and is indicated on an alternating-current voltmeter. The voltage from the control circuit goes through a filter of the high pass type, which is used to eliminate

low-frequency pickup. This pickup may be from either the power line or from the leads to the motor in a powered model. The output of the filter is connected to the amplifier on the main chassis. The amplified voltage is fed into a rectifier and the direct-current output actuates the large fan-shaped meter on the control box (fig. 2).

The oscillator and the power supply for both the amplifier and the oscillator are mounted on the main chassis and the necessary wiring is brought by cable to the control box. To reduce the effect of line voltage fluctuations on the operation of the instrument, an alternating-current voltage regulator in the supply line is used. The main line switch and a pilot light are also in the control box. In this way all the controls needed for operation of the balance are brought directly to the operator for convenience of operation.

C. Operating Experience

This electrical balance has been used in both the 7- by 10-foot tunnel and the 19-foot pressure tunnel of the NACA at Langley Field. In the tests made initially in the 7- by 10-foot tunnel, a certain sensitivity drift was apparent which necessitated frequent calibrations. However, the test results were very promising and a revised balance was built in which this drift was eliminated. This balance was used at the 19-foot pressure tunnel with very satisfactory results on tests of a tail-plane model. Some time before the tests were run, the gage unit was installed in the test surface. The complete balance and the test set-up were made outside the tunnel for calibration purposes. The main surface was fixed rigidly and moments were applied to the control surface by hanging known weights on a wire fastened to it at a measured distance from the hinge line. The balance was checked over a period of one week by taking calibration curves at frequent intervals. The results of these calibrations indicated that the balance would reproduce readings to ±2 percent of full scale on the meter.

The temperature rise in the pressure tunnel may be quite high when testing is continued for a long time, amounting at times to 50° F. Accordingly, the gage unit was designed with a view to minimizing the temperature

effect. As a test, the temperature of the gage unit was raised 40° F by placing a large soldering iron about 6 inches below it. No noticeable deflection of the meter occurred. It is felt that these test conditions are more severe than would occur in normal operation because of the uneven localized temperatures.

The model was installed in the tunnel and check calibrations were made from time to time. These calibrations all compared favorably with previous data. The engineers conducting the tests found the meter easy to read and adjustments simple to make. Adjustments to the gage unit had to be made only when the angle of the control surface relative to the main surface had to be changed. A typical set of curves showing data taken with this balance is given in figure 3. The installation of the gage unit in the tail-plane model is shown in figure 4. The spool-like member is used as a torsion spring and the coils are held in clips connected to the spool flanges. The elevator hinge moment causes a twist in the body of the spool and the relative motion of the flanges changes the gage-unit coupling.

In addition to this installation, two trials have been made of this balance for determining the torque in powered models. In these tests the model motor was mounted in ball bearings and restrained by a spring member. The deflection of the spring provided variable coupling at the gage unit. Difficulty from pickup was encountered as the stray flux from the motor coupled into the coils. The filter in the control box was inserted to eliminate the pickup. A completely satisfactory spring has not yet been built for this purpose, as the effects of temperature rise and thrust of the propeller on the spring and cradle combination gave spurious deflections.

Work on springs and mountings suitable for use for torque determinations is going forward in an effort to perfect this application.

Development of multichannel apparatus which will enable the operator to read the moments at several points in the model with little or no adjustment to the control box is also being carried on.

With the multichannel apparatus, one channel will be used for torque measurements. In this way there will be

available means for taking hinge-moment and torque data while regular tests are being run, with no waste of time.

PART II. CONSTRUCTIONAL DETAILS

A. Gage and Balance Unit Coils

The coils which are assembled to make the gage and balance unit transformers are individually wound on iron cores. Figure 5 shows the core shape of a single coil. The core is formed of laminations of transformer silicon steel approximately 0.014 inch thick. These laminations should be thin to keep losses down. The laminations of an old transformer may be used to make these cores. For a complete balance, four cores are needed.

The coils are wound with No. 36 A. W. G. enameled manganin wire. The use of manganin wire serves to give a relatively high ratio of winding loss to iron loss. This minimizes the effect of variation of iron loss with temperature. As manganin wire has a very low temperature coefficient of resistance, resistance variations with temperature are negligible.

It is important that the coils be layer-wound and that all coils be similar. All the coils should have a resistance of approximately 1000 ohms when completed and all should have approximately the same number of turns. The winding may be insulated from the core with a thin layer of fish paper. It is advisable to make a small jig, consisting of two clamps for the core ends, with end plates to fix the winding length, for winding the coils in a small lathe. Figure 6 shows such a jig and in it a partially wound coil. One end of the jig is arranged for clamping in the lathe headstock; the other is countersunk for the tailstock dead center.

After winding, the coils are impregnated with an insulating varnish and baked. The baking helps relieve stresses which are set up in winding and aids in stabilizing the winding resistance. Leads of heavier wire should be soldered to the coil ends and firmly cemented for greater mechanical strength.

B. Mechanical Structure of Gage Unit

Designing of the spring member and the coil clamps for the gage unit presents certain problems which must be carefully handled for satisfactory operation of the balance. The balance itself gives an indication only of change in coupling between the two coils of the gage unit. It is the function of the spring member to transform the load on the surface to a deflection, which will be indicated by the balance. If the spring has any hysteresis, the indicated hinge moment will exhibit this hysteresis. If the hinges of the control surface have excessive friction, this friction will give the appearance of hysteresis in the indication. The importance of eliminating friction and hysteresis in the mechanical design may be appreciated when the full-scale movement of the coils of 0.010 inch is considered.

We have found in practice that if the spring is so designed that the maximum unit stress does not exceed 20 percent of the elastic limit of the material there will be no noticeable hysteresis caused by the spring.

No connections, as for clamps to hold the coils, should be made to parts of the spring member which are under full stress in the loaded condition. If practicable, it is desirable to machine the spring and its mounting lugs of one piece of material and eliminate the effect of weld metal at stressed locations. Figures 7 and 8 show a spring member of this type. This unit is mounted inside the surface with the rod on the hinge line. The plates at the end of the rod are bolted to the control surface of the model. The fork at the center of the rod is pinned to a link which is connected at the far end to the fixed surface. All possible precautions are taken to insure friction-free hinges on the control surface. In this way the surface load is transmitted through the link to the fork on the rod, and through the rod to the plates and the control surface. The coils are clamped, one to the fork extension as shown, and the other below it to the plates and main surface.

The rod is stressed both in torsion and as a centrally loaded fixed end beam. The design of the member is such that the deflection caused by the torsional load is chiefly the one that must be considered in operation. This deflection, or twist of the rod, serves to move the

coils toward or away from each other and provides the variable coupling at the gage.

Several gage units have been constructed, using a torque rod as the spring but with the coil clamps attached to the rod by a split clip. This is reasonably satisfactory if the point of coil clip attachment is on an extension of the rod which is beyond the point of application of load. If the rod is clamped to the main surface or the linkage from the control surface by a split clamp, there will be slipping at the clamping point and the operation will not be satisfactory. On an installation of this sort it was not possible to eliminate slippage by taper pins and only brazing of the clamp and rod sufficed. However, this introduced brazing material as a portion of the spring and there was hysteresis as a result of the inelastic character of the material.

Figure 4 shows a gage unit used at the 19-foot pressure tunnel. In this unit the spring consists of a pair of spools. The central portion of the spool deflects under the load. The attachment to the model is made with bolts through the flanges, where the stress is low and clamping effects are negligible. The clips which hold the coils are also mounted to the flanges. This permits the removal of the spool and coils as a unit and the setting of the coils will not be disturbed. Several sets of holes are provided in the flanges to allow for the variation desired in angular setting between main and control surfaces.

The coil clamps and the mounting rods should be rigid enough to prevent vibration of the coils. Typical coil clamps can be seen in figures 4, 7, and 8. They can be made of brass or aluminum but preferably not steel. They should be arranged to hold the coils with a separation of approximately 0.050 inch or 0.060 inch. (See fig. 5.) The design deflection of the spring under the maximum anticipated load should be 0.010 inch measured at the gage coils. Limiting this deflection prevents the calibration from becoming excessively nonlinear. However, too small a deflection should not be used because spurious deflections in either the gage unit or the balance unit due to mechanical creep or thermal warping may amount to an appreciable percentage of the total deflection.

C. Mechanical Structure of Balance Unit

A typical balance unit is shown in figure 9. As can be seen from the photograph, it consists of two coils clamped to a fixed plate and a movable arm. The construction shown was adopted because it affords good control of the setting of the moving coil. The screw which moves the flexible arm has 40 threads per inch for fine adjustment. The setting may be fixed by the split-nut and clamp-screw arrangement. The complete unit may be made of brass.

D. Main Chassis

1. General

The power supply, oscillator, and amplifier are all built up on a metal chassis 10 by 17 by 3 inches. All components are listed on pages 17, 18, and 19. The three units are separated on the chassis, with the purpose in mind of reducing coupling between the oscillator and the amplifier. Cables from the control box to the main chassis are of the two-wire, shielded-microphone-conductor type. Connections are made by two contact-amphenol-shielded microphone connectors or similar connectors. The wiring should be arranged so that the interaction between units will be at a minimum.

2. Power Supply

(See fig. 10.)

The power supply is of the electronically regulated type and supplies the direct current and the filament voltage for the oscillator and the amplifier. The 115-volt input cable should be long enough to reach the voltage regulator, which in turn is connected to the control box. The voltage regulator is of the saturable core reactor type as built by Raytheon, Thordarson, U.T.C., or Sola and should be capable of continuous duty with 150 VA load. The power supply presents no wiring difficulties and can be assembled quickly. The resistors R_2 and R_4 should be accessibly mounted on the chassis. The shafts should be slotted for screw-driver adjustment, because once they are set they will not have to be touched. It will be

found that R_4 roughly sets the output voltage and R_2 controls the regulation. Successive adjustments of R_4 and R_2 will permit the desired output voltage and regulation to be obtained. The output voltage should be set to 240 volts and the regulation should be such that input voltage variation from 105 to 125 volts alternating current will not change it. No external connections to the power supply output are necessary since all connections to the supply are made in the chassis. For more information see reference 1.

3. Oscillator

(See fig. 11.)

The oscillator is of the negative transconductance type with the frequency set by the values of CH_2 and C_7. The values for the circuit components should be as given in the component list to insure satisfactory operation. CH_2, which is the tuned circuit inductance, should not be replaced by an equivalent inductance as the resistance of the coil will, if changed, affect the oscillator operation. The frequency of the oscillator is approximately 2000 cycles per second. The power amplifier stage utilizes an ordinary output transformer. The 500-ohm output is used and a noninductive resistor R_{19} is used in the control box which, with R_{20} and R_{21}, and the coils, forms the correct load for the output tube. For further information on this type of oscillator see references 2 and 3.

4. Amplifier

(See fig. 12.)

The amplifier is a simple resistance capacity coupled amplifier with a full wave rectifier in the output. A certain amount of negative feedback is used to stabilize the gain and reduce the effects of tube changes and voltage swings on the output. In construction the major precautions are adequate shielding, particularly of the input grid lead and resistor, and correct phasing of the feedback voltage. The input grid resistor can be shielded

completely with a piece of braid. The correct phasing of the feedback voltage is easily obtained by connecting C_{15} and the ground lead to the output side of T_3. If oscillation occurs, reverse the two leads. The connection which results in no oscillation is the proper one.

The choke CH_3 and condenser C_{12} are used to filter the direct current to the amplifier and eliminate from it any ripple introduced by the oscillator.

The rectifier is fed from the output tube by an audiotransformer. This transformer is connected as a step-down unit, the reverse of its usual connection.

E. Control Box

(See figs. 2 and 13.)

The photographs show the panel layout of the control box. The knurled heads at the very bottom of the box are for the balance unit. The vernier adjustment on the oscillator is directly under the meter. The coarse adjustment is set by a screw driver through the side of the box. The position of the on-off switch, pilot light, and check-read switch may be noted. The leads are all brought in the rear of the box. The wiring is shielded as indicated and the base of the balance unit grounded. Plugs and sockets are used for making connections to the gage cable and the cables from the main chassis. It should be noted that the gage primary and secondary are run in separate two-wire shielded cables but connect to the control box through a four-conductor polarized connector.

F. Assembly and Operation

To check the operation of the balance, a set-up of the gage unit should be made so that it can be loaded as it will be in the model. The coils are mounted in the clips of the gage and balance units with an air gap of approximately 0.050 inch to 0.060 inch. The wiring is run in from the control box to the coils.

The amplifier can be used as a vacuum tube voltmeter to check the connections for correct polarity of the

secondaries. The following procedure will enable the operator to make the initial balancing adjustments of the coils.

The air gaps at balance and gage units are set to be approximately equal. The primary coils are connected in parallel and the secondary coils are connected in series, as shown in figure 13. The read-check switch is thrown to "read." R_{22} may be omitted until the adjustments are complete. R_{24} is a precision wire wound resistor and may be a decade resistance box with one-ohm steps if one is available. In any case a variable resistor of about 1000 ohms maximum is required at R_{24} for initial adjustment. The connections between the main chassis, voltage regulator, and control box are made except for the cable from the control box to the amplifier input.

A cathode-ray oscillograph is a very useful testing aid at this point. The power is turned on and the power supply checked for proper output voltage. The oscillator voltage should be set by R_{20} to about 8 volts. The wave shape can be checked visually with the oscillograph. It should be nearly pure sine wave. The reading on the direct-current output meter should not be more than 5 percent of full scale. If the meter goes to full scale when the balance is turned on, check the amplifier feedback phasing as described previously. If this does not eliminate the high meter reading, check to see that the input tube is not picking up stray voltages and amplifying them. There will be a meter reading of a few percent remaining after all these points are correct. This meter reading is caused by the rectifier tube and is to be expected.

If an oscillograph is available, use a pair of test prods and observe the secondary voltage of the balance unit. Without changing the settings of the oscillograph, check the secondary voltage of the gage unit. These two voltages should give about the same deflections on the screen. If the two are very different, it will be necessary to move one of the coils until the two secondary voltages are about equal. The oscillograph leads are then placed across the two secondaries in series. The reading should then be small as compared to the voltage of a single secondary. If the reading is not small, reverse the leads coming from the gage secondary to the control box. In this box the two coils are placed in opposition and are approximately balanced.

If no oscillograph is available, then set R_{24} to zero and connect the amplifier input cable. The meter reading should not change. Slowly increase R_{24} from zero while watching the output meter. It should be possible to raise it to over 100 ohms without the meter going off scale. If the meter goes off scale with R_{24} very small, reverse the gage secondary leads. This should permit raising R_{24} to a higher value before the meter reaches full scale. If it still appears that the resistance is too low, the coils should be adjusted, as the secondary voltage may be badly out of balance.

If the coils have been set approximately with an oscillograph, the amplifier connection can be made and R_{24} set to about 100 ohms. When either method has been used, it should be possible to make the output meter vary from full scale to a minimum about 5 to 10 percent of full scale by turning the adjusting screw on the balance unit.

The sensitivity of the balance may be set in the following way: R_{24} is set at, say, 100 ohms. The balance unit is then set to give midscale reading on the meter. The surface is loaded by weights suspended on a wire so that the hinge moment is calculable. The anticipated hinge moment being known, the weights are put on until this hinge moment deflects the spring of the gage unit, which causes a meter reading either up scale or down scale from the midpoint. Should the meter go off scale to the right or go down scale to a minimum and reverse before the full anticipated moment is applied, the sensitivity is too high and must be reduced. The sensitivity is lowered by reducing R_{24}, resetting the balance unit for midscale deflection, and checking as described. The difficulty in getting the coils to balance exactly is what causes the minimum reading as the meter goes down scale. This minimum should not be higher than 5 or 10 percent of full scale. The sensitivity should be set so that at full load the meter reading is several divisions above the minimum on the low end. This means that full load in the opposite direction will not deflect the meter full scale.

When the desired sensitivity is set, the check resistor (R_{22}) can be set. Also R_{22} may be a decade box (0 to 10,000 ohms in 10-ohm steps), or a fixed wire wound resisto

can be used after the proper value has been found with a variable resistor, as follows: R_{22} is set with the switch (SW_1) in the check position to give midscale reading. The operation of the check circuit is covered in part III of this report.

When the sensitivity and check resistors have been set, a calibration of the balance, giving hinge moment versus meter reading, may be made. If, in the particular case, the load on the spring is such that it always will be in the same sense, then the balance point may be set to permit use of most of the meter scale. For example, suppose the meter minimum reading to be 8 divisions, with 100 divisions for full scale and the moment to be measured plus or minus 20 pound-feet. The balance unit would be set to give 50 as a meter reading at zero hinge moment. The sensitivity would be set so that the 20 pound-feet would cause a deflection up scale to 90 and down scale to 10.

If the moment were +5 pound-feet and -25 pound-feet, then for the same minimum of 8 divisions the zero hinge moment reading would be set to 85. Then the sensitivity would be adjusted to give a reading of 100 with +5 pound-feet and 10 with -25 pound-feet.

PART III. ANALYSIS OF CHECK CIRCUIT

With reference to figure 14, an elastic member S is so arranged that its yield in response to the hinge moment alters the primary to the secondary coupling of the gage unit G. The change e_1 in the secondary voltage is, as has been mentioned, a measure of the hinge moment. The balance unit B is connected in series opposition so that the net voltage of the two is the absolute value of the voltage difference $e_{diff} = |e_o + e_1 - e_b|$. It is clear that e_b could be made to cancel* e_o. the

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*Approximately. Practically, the cable to the gage unit produces an impedance asymmetry which makes a perfect balance difficult even with the use of correcting capacitors. Harmonics in the oscillator output aggravate the difficulty.

output voltage of G for zero hinge moment, so that the net output voltage would be simply e_1, the voltage due to the applied hinge moment. It is preferable, however, to operate with a deliberate unbalance ($e_b > e_o$ or $e_o > e_b$) of such amount that the meter reads midscale ($E_m/2$) for zero hinge moment; that is, for $e_1 = 0$. Then hinge moments of one sign will cause the meter to read up scale and hinge moments of the opposite sign will cause the meter to read down scale. Changing the sign of the difference $e_o - e_b$, by changing the balance unit air gap, will reverse the relationship so that hinge moments which read up scale before will read down scale, and conversely.

A part αe_b of the balance unit voltage e_b may be picked off the voltage divider R_1, R_2 to serve as a reference voltage for standardizing the apparatus at any occasion to its original calibration despite secular changes which may have occurred in oscillator voltage or frequency and in amplifier gain. For let αe_b be set equal to $|e_o - e_b|$, which, we have seen, will produce a deflection $E_m/2$ in the output meter, and let this occur for a particular oscillator voltage e_{po}, oscillator frequency f_o, and amplifier gain G_o. We then have

$$G_o \ \alpha e_b = E_m/2 \tag{2-1}$$

But experimentally the secondary voltages are closely proportional to the oscillator voltage and frequency. And since the amplifier output voltage E is in turn proportional to the secondary voltages, the proportionality constant being the gain G, we may write

$$E_{check} = G\left(\frac{e_p}{e_{po}}\right)\left(\frac{f}{f_o}\right)\alpha e_b \quad \left\{\begin{matrix}\text{Reading in the} \\ \text{"check" position}\end{matrix}\right\} \tag{2-2}$$

where e_p, f, and G are the existing oscillator voltage, oscillator frequency, and amplifier gain, respectively, at the time under consideration. If, now, we adjust any one of these three quantities so that $E_{check} = E_m/2$, we have from equation (2-2),

$$G\left(\frac{e_p}{e_{po}}\right)\left(\frac{f}{f_o}\right) = \left(\frac{E_m}{2}\right)\left(\frac{1}{\alpha e_b}\right) \tag{2-3}$$

But the output voltage in the "read" position with an applied hinge moment is

$$E_{read} = G\left(\frac{e_p}{e_{po}}\right)\left(\frac{f}{f_o}\right)\left|e_o - e_b + e_1\right|$$

$$= G\left(\frac{e_p}{e_{po}}\right)\left(\frac{f}{f_o}\right)\Big|\left|e_o - e_b\right| \pm e_1\Big| \tag{2-4}$$

and substituting (2-3) and the relation $\alpha e_b = \left|e_o - e_b\right|$ there results

$$E_{read} = \frac{E_m}{2}\left(\frac{1}{\alpha e_b}\right)\left|\alpha e_b \pm e_1\right| = \frac{E_m}{2}\left|1 \pm \frac{e_1}{\alpha e_b}\right| \tag{3-1}$$

Since this final equation (3-1) contains neither e_p, f, nor G, it appears that the adjustment to make $E_{check} = E_m/2$ has rendered the meter reading independent of the oscillator voltage, oscillator frequency, and amplifier gain.*,**

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*Strictly speaking, the meter reading is independent of these three quantities individually, but not of their product; but the value of the product has been properly fixed by the mentioned adjustment.

**In this analysis the meter deflection has been assumed directly proportional to the r.m.s. amplifier output voltage E so that $Rdg = kE$, and the constant k was absorbed into the amplifier gain G. The conclusion of independence of the meter reading of e_p, f, and G still holds for a nonlinear relationship if this relationship is of the form $Rdg = F(kE)$, where F may be any single-valued function of kE, and k is the only meter parameter which may vary with time: it is dependent almost solely on the rectifier characteristic. Diode rectifiers come much nearer to permitting fulfillment of this condition than do copper oxide rectifiers.

While the analysis permits the adjustment to be made by variation of either e_p, f, or G, adjustment of the frequency f is impracticable, and of the other two we have chosen to vary e_p, the oscillator voltage.

While the equations obtained above for the simplified circuit of figure 14 are modified by the presence of the shunt elements R_{24}, F_1, R_{25} in the actual circuit of figure 13, the conclusions are valid for both circuits.

COMPONENTS

R_1	20,000 ohm, 5 watt
R_2	300,000 ohm, 2 watt, potentiometer
R_3, R_{11}, R_{16}	0.5 megohm, 1 watt
R_4	100,000 ohm, 2 watt, potentiometer
R_5, R_{18}, R_{23}	0.1 megohm, 1 watt
R_6	1500 ohm, 1 watt, wire
R_7	0.13 megohm, 1 watt
R_8	9000 ohm, 1 watt
R_9, R_{15}	0.25 megohm, 1 watt
R_{10}, R_{17}	1000 ohm, 1 watt, wire
R_{12}	1250 ohm, 1 watt, wire
R_{13}	500 ohm, 1 watt, wire
R_{14}	1.15 megohm, 1 watt
R_{19}	750 ohm, 10 watt, wire, noninductive
R_{20}	1000 ohm, 2 watt, wire, potentiometer
R_{21}	100 ohm, 2 watt, wire, potentiometer

R_{22}, R_{24}	decade box, see construction notes
R_{25}	5000 ohm, 1 watt
C_1, C_2	8-8 microfarad 450 volt electrolytic
C_3	0.25 microfarad 600 volt paper
C_4, C_8	0.1 microfarad 600 volt paper
C_5, C_9, C_{10}, C_{14}	4 microfarad 250 volt electrolytic
C_6, C_{12}	8 microfarad 450 volt electrolytic
C_7	0.072 microfarad 600 volt paper
C_{11}	0.04 microfarad 600 volt paper
C_{13}	0.005 microfarad 600 volt mica
C_{15}	0.5 microfarad 600 volt paper
T_1	Stancor P-6294
T_2	Thordarson T 67 S48
T_3	Thordarson T 17 A02
T_4	Balance unit
CH_1	Thordarson T44C02
CH_2	Hammarlund RFC85
CH_3	Hammarlund RFC250
V_1	5Z3
V_2	2A3
V_3, V_5, V_7	6J7
V_4	874

V_6, V_8	38
V_9	6H6
F_1	General Radio - High pass filter, 5000 ohm, 1000 cycle, type 830 H
f_2	$1\frac{1}{2}$ ampere fuse
SW_1	S.P.D.T. Jack-type switch
SW_2	S.P.S.T. Toggle switch
S_1	110 volt receptacle
P_1	110 volt plug
L	110 volt $7\frac{1}{2}$ watt signal lamp
VM	0-15 volt a-c. rectifier-type voltmeter Weston model 301 or GE-type D046
d-c. Output meter	Weston Model 273 0-1 milliampere.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

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2. Brunetti, Cledo: The Transition Oscillator. Proc. Inst. Rad. Eng., vol. 27, no. 2, February 1939, pp. 88-94.

3. Brunetti, Cledo: A Practical Negative Resistance Oscillator. Rev. Sci. Instr., vol. 10, no. 3, March 1939, pp. 85-88.

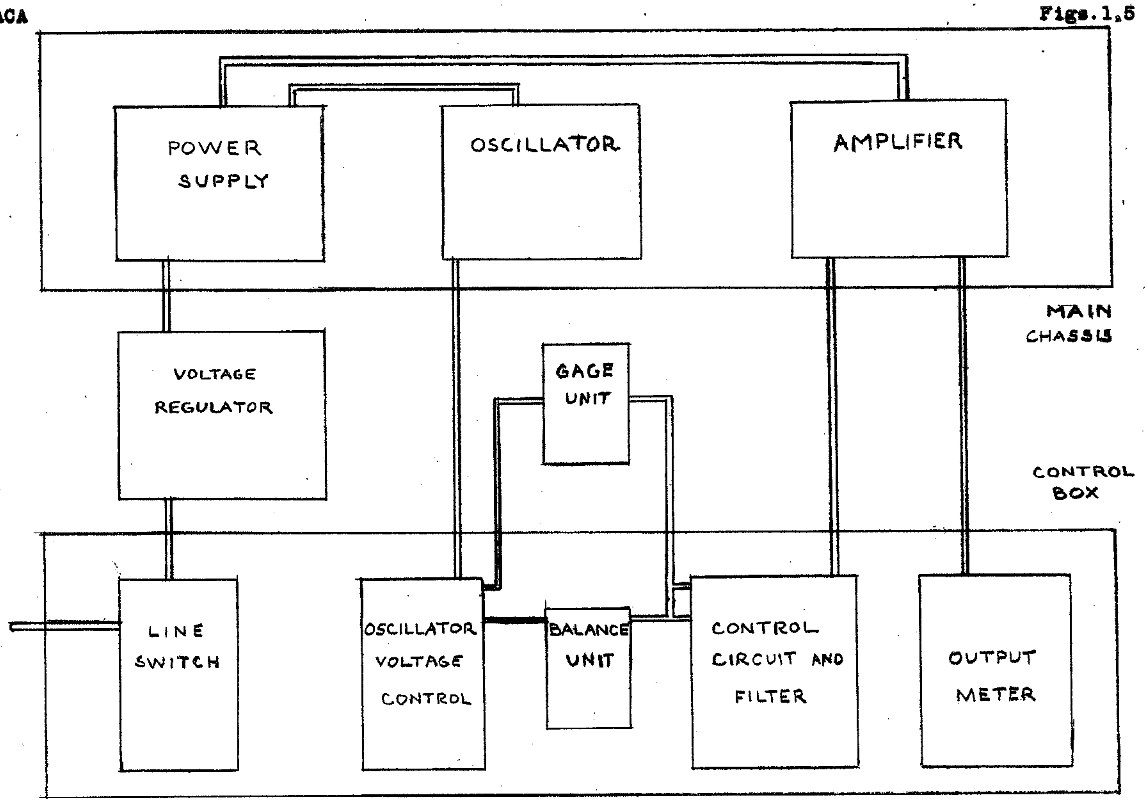

FIGURE 1. - BLOCK DIAGRAM.

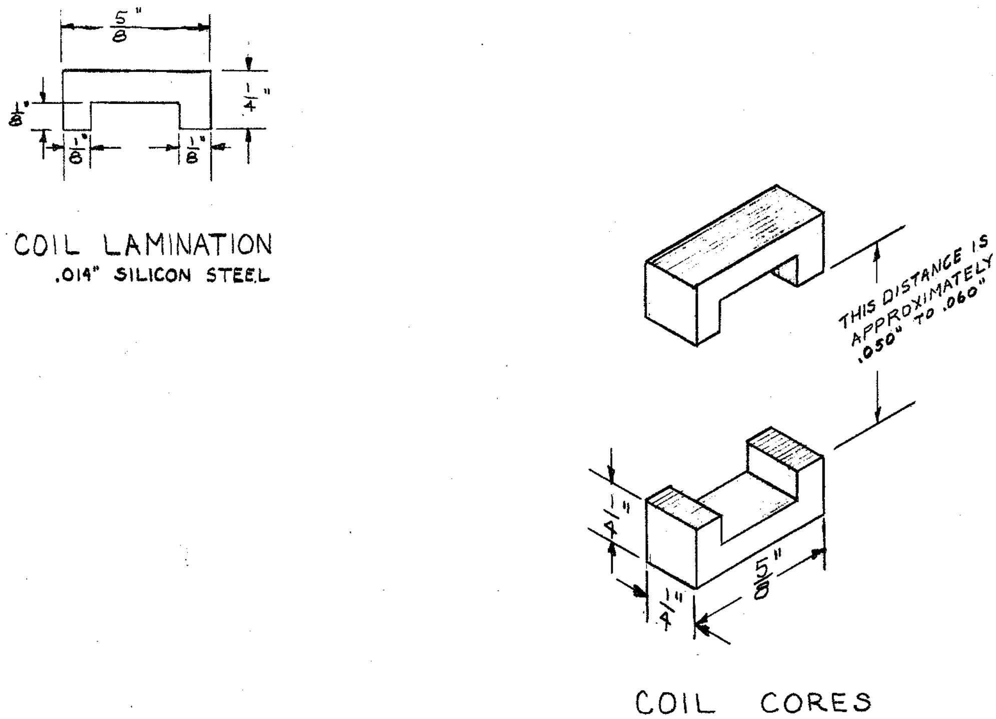

FIGURE 5.- COIL LAMINATIONS AND CORES.

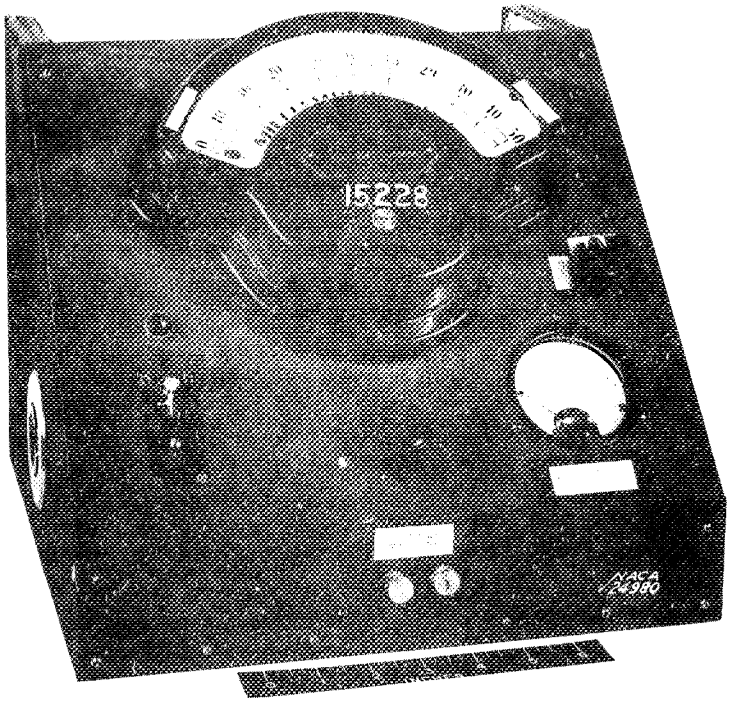

Figure 2.- Control box.

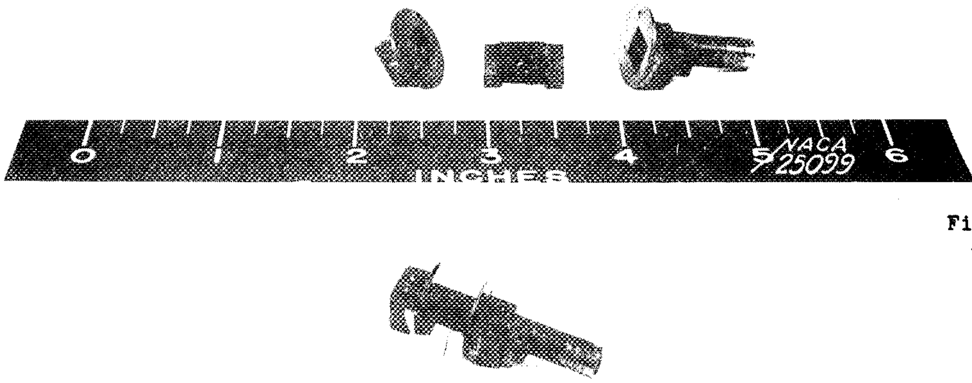

Figure 6.- Coil winding jig.

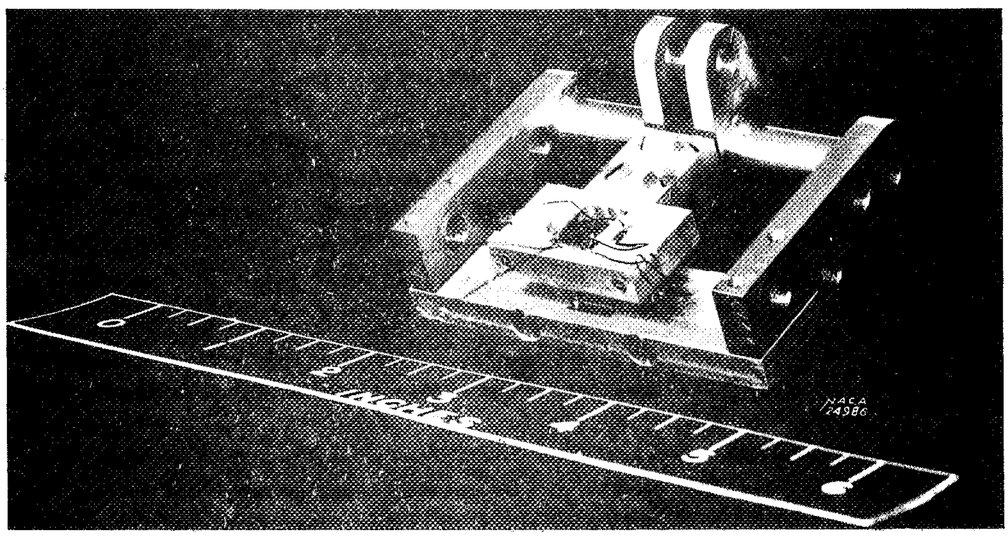

Figure 7.- Gage unit.

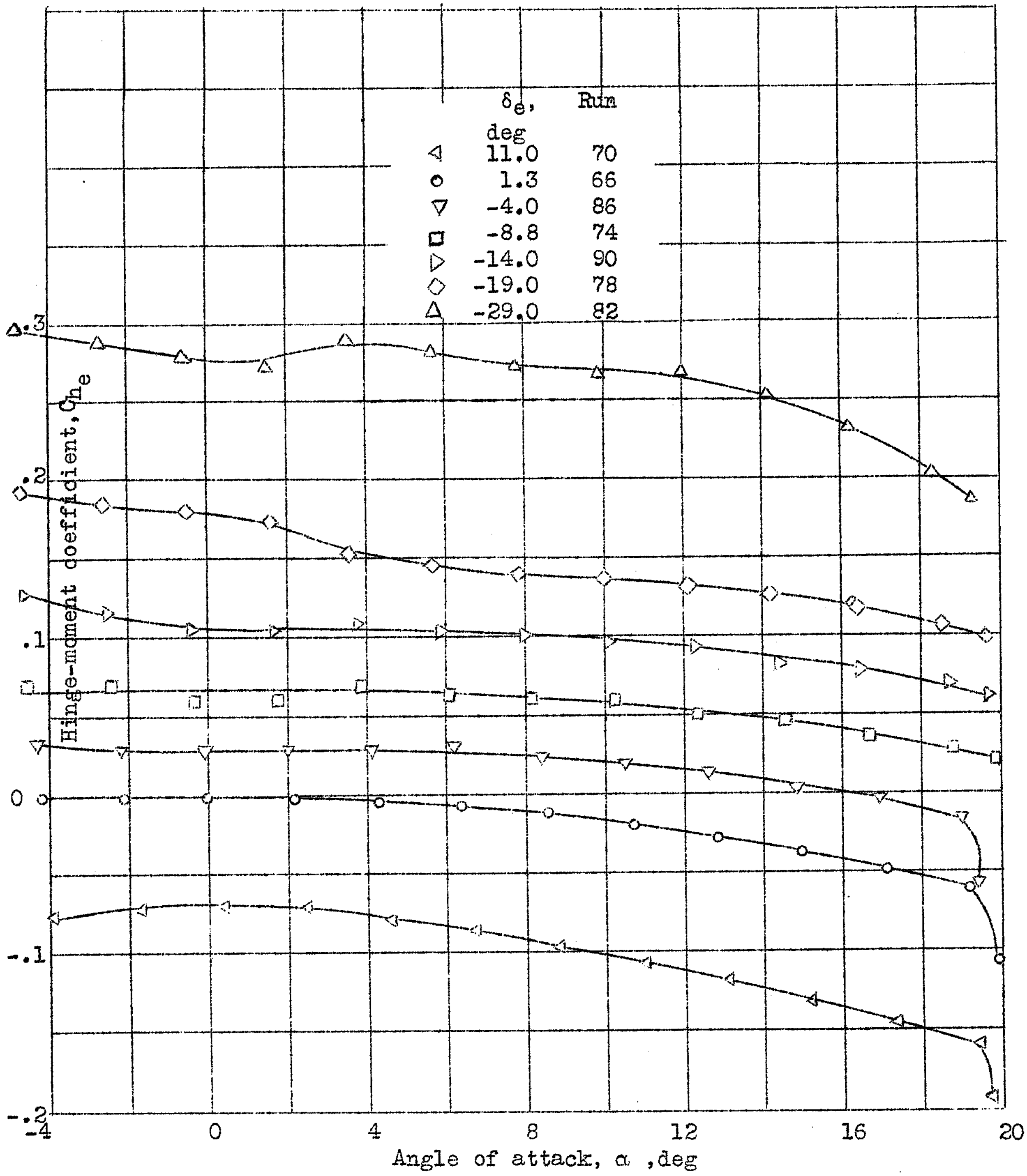

Figure 3.- Data obtained with balance.

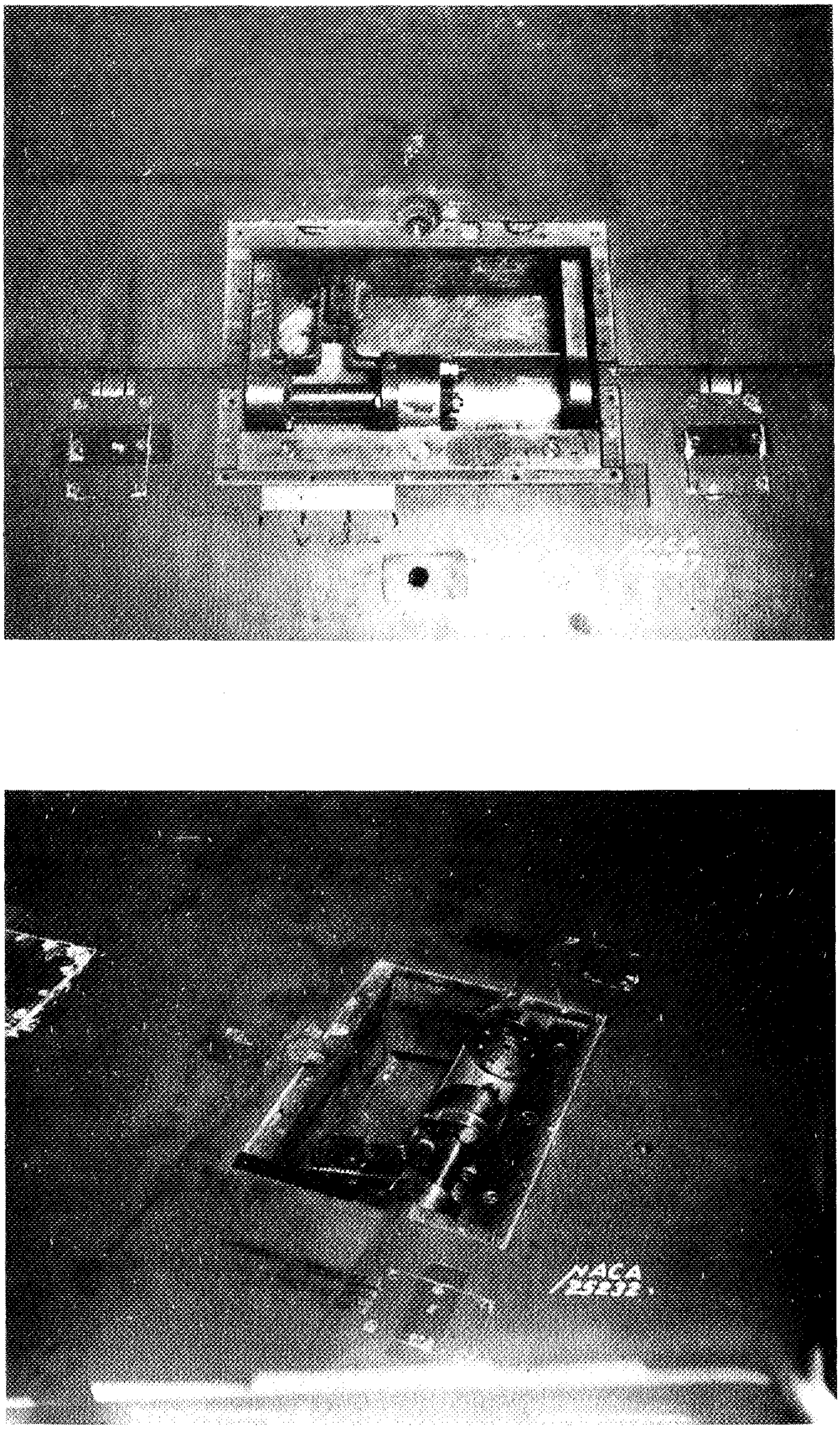

Figure 4.- Installation of gage unit.

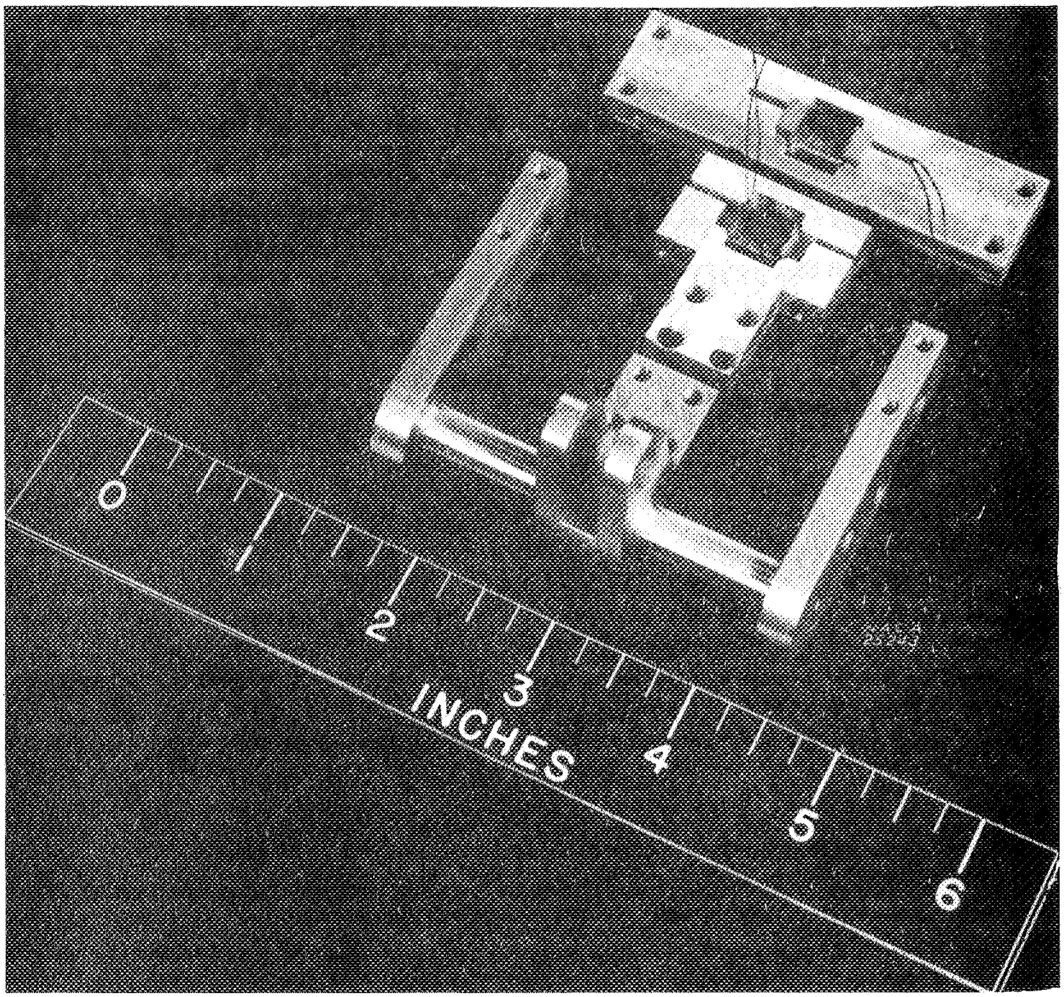

Figure 8.-Gage unit.

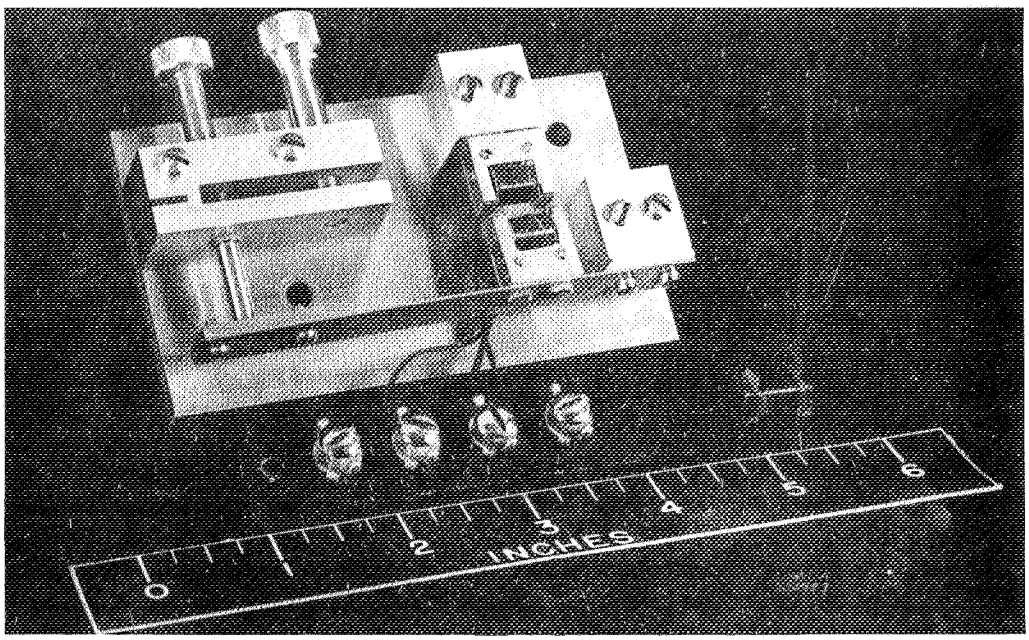

Figure 9.-Balance unit.

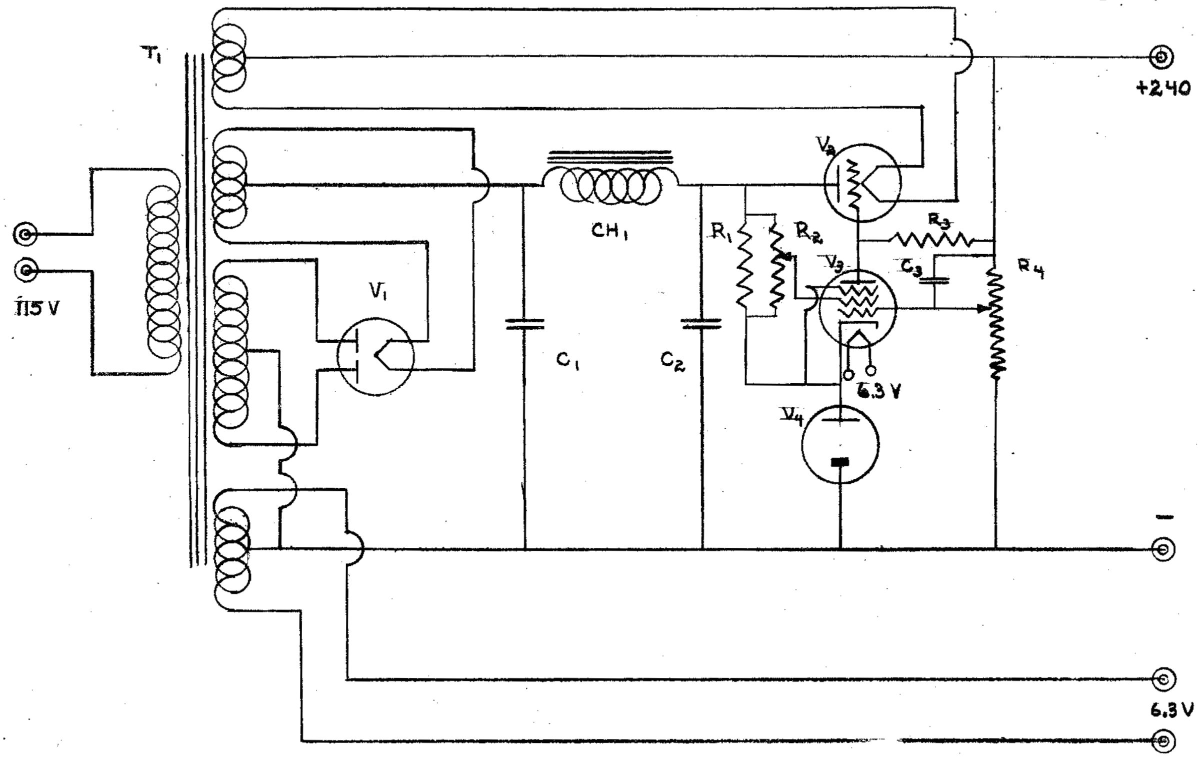

FIGURE 10. - POWER - SUPPLY WIRING DIAGRAM.

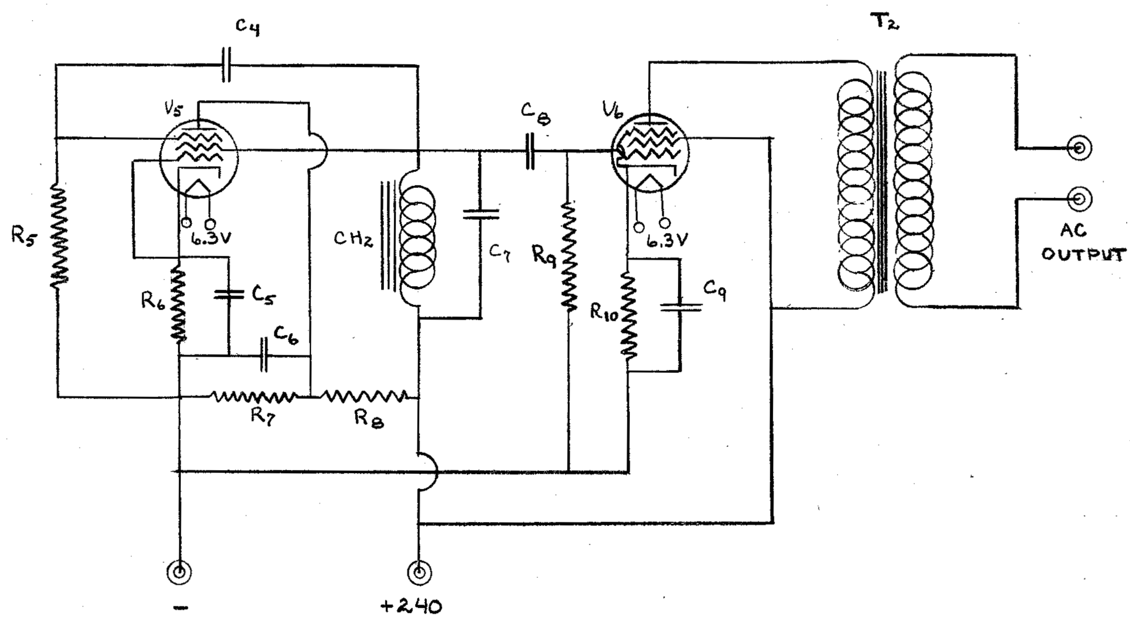

FIGURE 11. - OSCILLATOR WIRING DIAGRAM.

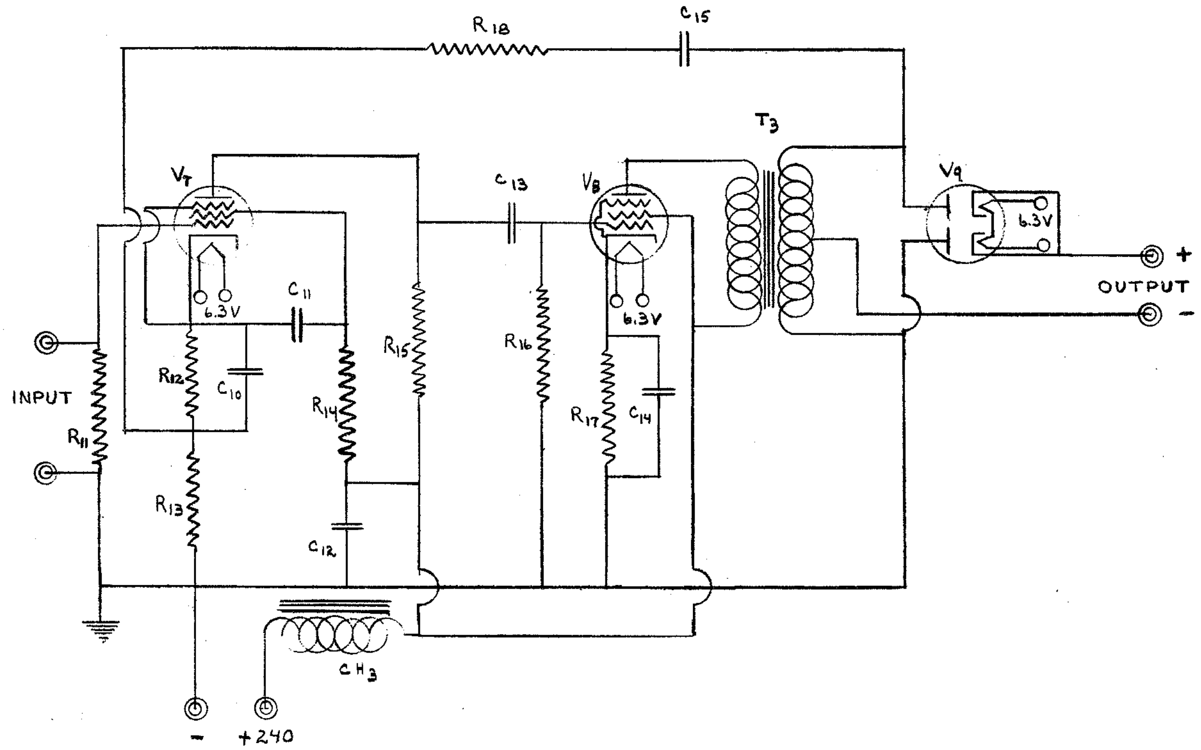

FIGURE 12. - AMPLIFIER WIRING DIAGRAM.

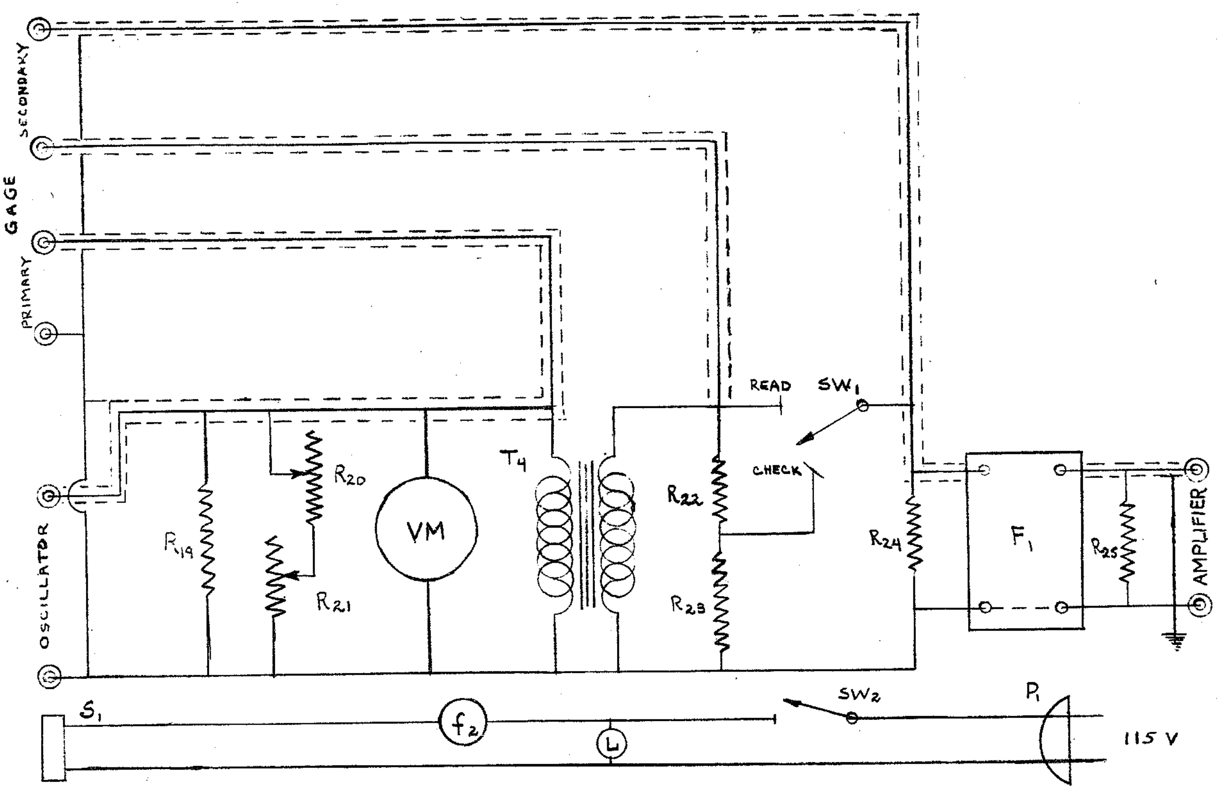

FIGURE 13. - CONTROL - BOX WIRING DIAGRAM.

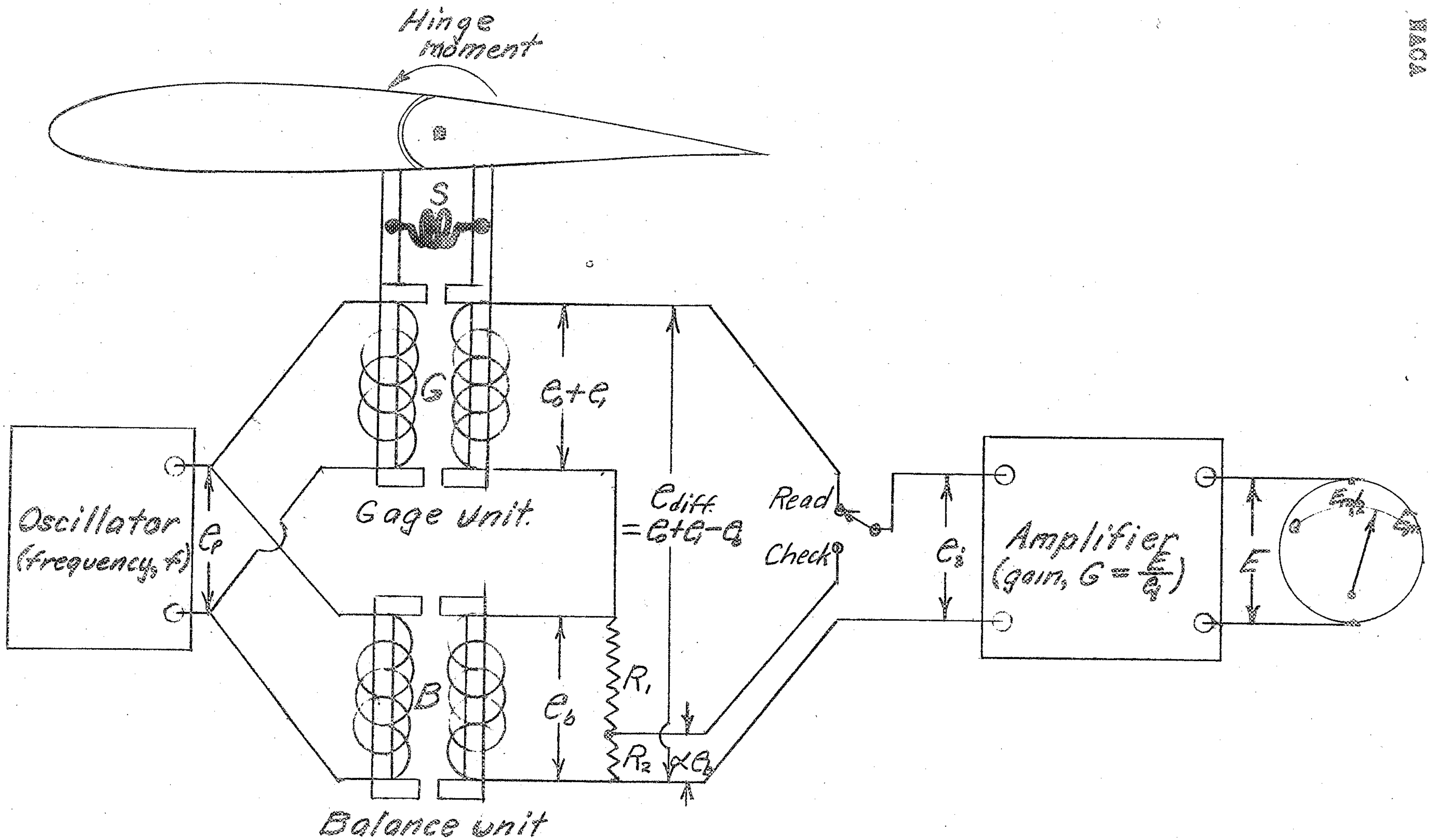

FIGURE 14. — CHECK CIRCUIT ANALYSIS.